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Finite-aperture corrections to photocount statistics of Gaussian light

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Experimental results on the effects of finite-aperture detectors on the statistics of Gaussian light are presented. A laser illuminating a rotating diffusing screen was used to provide a source with a long coherence time, and the photoelectron statistics of a photomultiplier detector were recorded electronically. The data, which were taken with circular apertures and a linear polarizer in front of the detector, agree with calculations of factorial cumulant correction factors published by Cantrell and Fields.

Theoretical analyses of measurements of photoelectron counting statistics usually assume that the area of the photodetector in use is negligibly small compared to a coherence area of the field under study. In practice, this can be an unrealistic assumption. The use of detectors having sufficient area to give a useful count rate often results in significant spatial averaging of the field intensity, and thus in a reduction in the level of correlations from that which would otherwise be expected theoretically.

Cantrell and Fields[1,2] have presented a calculation of the correction factors required to reduce experimental data to point-detector values. Their correction factors S_N were given in terms of the factorial cumulants of the photoelectric counting distribution of partially polarized Gaussian and Gaussian-plus-coherent light. Numerical results up to order six were given for the case of circular apertures and fully polarized Gaussian light. In the present paper we present experimental data intended to test these theoretical results.

An artificial source of radiation having a long coherence time was made by shining a linearly polarized 1.8-mW helium-neon laser (Spectra-Physics model 133-P) on a moving diffuser screen. The scattered light passed first through two circular apertures (of radii r_1 and r_2) separated by a distance R, then through a linear polarizer and a 0.6328-μm band-pass filter. The second aperture was imaged by a lens onto the photocathode of an ITT FW-130 photomultiplier tube (see Fig. 1). An auxiliary lens and aperture were used to provide spatial filtering of the incident laser beam and to control the intensity of the light falling on the diffusing screen.

The aperture radii were varied between approximately 0.1 and 2 mm, and their separation was varied between approximately 1 and 3 m. In this way the mutual coherence parameter

$$\kappa = k r_1 r_2 / z_1 R$$

was varied over a wide range. Here $k = 2\pi/\lambda$ and $2z_1 = 3.83171\ldots$ is the first zero of the Bessel function $J_1(z)$ (see Refs. 1 and 2).

The photomultiplier, which had an S-20 photocathode with an effective area 1 mm by 10 mm, was operated at room temperature. Its noise rate varied between 30 and 50 counts/sec. Signal rates varied from 5 to 70 kHz. The high signal-to-noise ratio allowed us to avoid the necessity of making background corrections.

The output of the photomultiplier was amplified and passed into a standardizing discriminator. The discriminator drove a gated 8-bit TTL binary scaler. TTL control circuitry automatically reset the scaler, and opened and closed the gate. After each count period, the scaler contents were read out and transmitted to a PDP-8/I computer, which was used to accumulate the histograms of photocount statistics. These histograms were accumulated over periods ranging from 5 to 20 min, during which time typically 10^6 scaler results were recorded.

Gate widths used varied from 125 to 1250 μsec. Our results did not depend on gate width, indicating a field coherence time greater than 1250 μsec. (The active spot on the diffuser was approximately 4 cm from the center of rotation of the diffusing disk, which made one revolution every 5 min.)

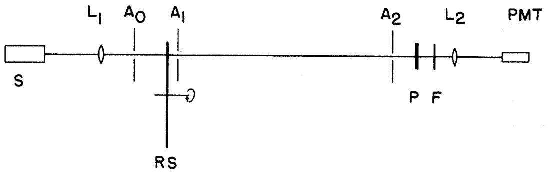

FIG. 1. Experimental arrangement. S, laser source; L_1 and A_0, lens and aperture used for spatial filtering and control of intensity; RS, rotating scatterer. A_1 and A_2 coherence-defining apertures, whose radii are r_1 and r_2, respectively. P and F, polarizer and interference filter; L_2, a lens which images A_2 onto the detector, PMT.

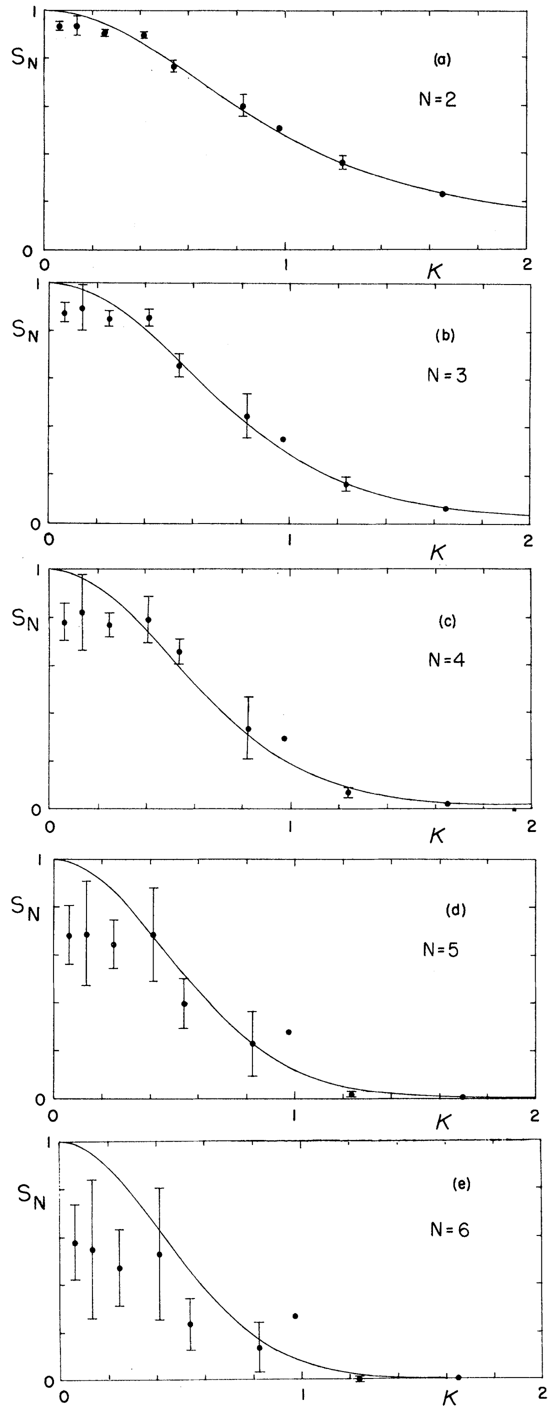

FIG. 2. Finite-aperture correction factors S_N, for $N=2$ to $N=6$, as functions of the coherence parameter κ.

The pulse-pair resolution of the discriminator-scaler system was measured to be 100 nsec. No rate-dependent effects were found over the range of count rates used in the experiment.

Normalized factorial cumulants[3] of the photocount distribution were calculated for each data run. For Gaussian light and point detectors these would all be equal to unity. The experimental values all lie below unity, reflecting the effect of the finite apertures. Our results are shown in Fig. 2, where the experimental values are compared to the theoretical results of Cantrell and Fields (solid lines).

The major source of experimental uncertainty was found to be a position-dependent systematic effect of the diffusing screen. Multiple runs made without varying the position of the active spot on the screen typically showed a factor of 2 to 3 less variation than is indicated by the plotted error bars. Groups of runs made with slightly perturbed diffuser positions varied by amounts which we have estimated and shown as the ranges of probable error in Fig. 2. (The two data points plotted without error bars represent data taken at only one diffuser position.)

Best results were achieved with a rigid plastic diffusing screen intended for rear projection. This plastic had a "stippled" appearance when viewed under a microscope, with grain sizes in the range of 2 to 10 μm. Attempts to use either commercially available ground glass or a type of plastic sheet used for diffusing theatrical lighting resulted in a worsening of the systematic variations. No improvement was found to be available by changing to reflected rather than transmitted light. All of the data presented here were taken with the rear-projection screen used as a transmission diffuser.

The data are seen to be in close agreement with the calculations of Cantrell and Fields for the lower-order cumulants, but decreasingly so for the higher-order results. We attribute this to the systematic non-Gaussian behavior of the field produced by our diffuser rather than to a discrepancy between the calculations and our experiment. Within the limitations set by our source, we confirm the numerical results of Refs. 1 and 2.

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[1] C. D. Cantrell and J. R. Fields, Phys. Rev. A 7, 2063 (1973). See the references cited in this paper for a general introduction to the literature.

[2] C. D. Cantrell and J. R. Fields, Princeton University Dept. of Physics Tech. Report No. 13 [Contract At(11-1)-3120, 1972] (unpublished). The numerical results with which we are concerned are given in greater detail in this report than in Ref. 1.

[3] R. F. Chang, V. Korenman, C. O. Alley, and R. W. Detenbeck, Phys. Rev. 178, 612 (1969).